ENHANCED EARTHING PERFORMANCE BY IMPROVED DESIGN AND GROUNDING MATERIAL PROPERTIES

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All praise to Allah SWT the Exalted, the Lord of universe.
Peace and blessings be upon our Prophet Muhammad
and upon his family and companions.

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To my beloved parents and family
for their prays, love, support
and encouragement.

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ABSTRACT

An enhance ground electrode (E.G.E.) is a portable grounding system that acts as an additional grounding system, designed for zero potential reference points. The E.G.E could eliminate the increasing of resistance in grounding conductor as it placed next to the electrical equipment, hence the grounding conductor is shortened. A prototype of E.G.E was developed in size measuring 19.5 cm x 19.5 cm x 11.5 cm and filled with selected grounding material, attached with a grounding electrode. Meanwhile, the grounding electrode was reviewed in terms of thermal conductivity electrode material, variation of soil resistivity with the electrode's depth, and effect on the number of grounding rods to ground resistance. The design of the electrode was selected based on heat dispersion that was simulated using the Finite Element Method (FEM) package. The four selected grounding materials chosen based on its resistivity value and physical composition which is; kaolin, sand, bauxite and coal. These materials were investigated using the morphology test, element composition test and correlation between water content and material resistivity test. Fabricated E.G.E was tested under lightning flashover conditions in a HV laboratory using an impulse test generator in order to validate its electrical performance and prolog life expectancy. Data obtained from laboratory tests indicated that bauxite is the best material for the proposed E.G.E system, compared to other materials by offering the lowest different percentage breakdown voltage comparable to native earth, which is around 1.27%. Besides that, bauxite gets 35% strikes during dry condition and 38% strikes during wet condition among three others material. It is hope this E.G.E sustaining a good performance as a grounding system.

ABSTRAK

Peningkatan Elektrode Pembumian (E.G.E) adalah pembumian mudah alih yang bertindak sebagai sistem pembumian tambahan yang direka sebagai rujukan titik sifar. E.G.E boleh menghadkan peningkatan kerintangan di dalam konduktor bumi kerana konduktor bumi telah dipendekkan memandangkan E.G.E diletakkan disebelah peralatan elektrik. E.G.E prototaip dibangunkan pada saiz 19.5 cm x 19.5 cm x 11.5 cm dan diisi dengan bahan asas pembumian yang diletakkan bersama elektrod pembumian. Sementara itu, elektrod pembumian telah dikaji dari segi kekonduksian terma bahan elektrod, perubahan pada kerintangan tanah terhadap kedalaman elektrod dan kesan keatas bilangan elektrod terhadap kerintangan tanah. Reka bentuk elektrod dipilih berdasarkan penyebaran haba yang telah disimulasi menggunakan Finite Element Method (FEM). 4 bahan asas pembumian telah dipilih berdasarkan nilai kerintangan dan komposisi fizikal iaitu kaolin, bauksit, pasir dan arang. Bahan-bahan asas ini telah disiasat menggunakan ujian morfologi, ujian komposisi elemen, dan hubungkait antara kandungan air terhadap ujian kerintangan bahan. E.G.E direka untuk diuji dibawah ujian kilat yang dijalankan di Makmal Voltan Arus Tinggi menggunakan penjana ujian impuls untuk mengesahkan prestasi elektrik dan penjangkaan jangka hayat. Data yang diperoleh dari ujian makmal menunjukkan bahawa bauksit adalah bahan yang terbaik di dalam system E.G.E, berbanding bahan asas yang lain kerana bausit menunjukkan nilai perbezaan peratusan terendah antara pembumian sedia ada iaitu sebanyak 1.27%. Selain itu, bauksit mendapat jumlah sebanyak 35 pancaran kilat semasa bahan dalam keadaan kering dan 38 pancaran kilat semasa bahan dalam keadaan lembap. Diharapkan agar E.G.E dapat mengekalkan prestasi yang baik sebagai system pembumian.

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LIST OF SYMBOL AND ABBREVIATIONS

GPR	Ground Rise Potential
E.G.E	Enhance Ground Electrode
HV	High Voltage
UTHM	Universiti Tun Hussein Onn Malaysia
FEM	Finite Element Method
AC	Alternating Currrent
DC	Direct Current
LAT	Lightning Air Terminal
XRF	X-ray Fluorescence
FESEM	Field Emission Scanning Electron Microscope
CEC	Cation Exchange Capacity
k	Thermal conductivity
ρ	Soil resistivity
R	Resistance
U_{50}	50% probability of flashover

CHAPTER 1

INTRODUCTION

1.1 Research background

A continuous supply of electricity is highly depending on the reliability of power system components that primarily consist of three main systems, which are the power generation, transmission and distribution systems. Power plants such as hydropower, coal-fired and gas-fired plants generate electric energy, which then transferred along transmission lines to the end-user. Figure 1.1 shows voltage from the generator stepped-up to the transmission voltage level line and finally stepped-down to the distribution voltage level line according to the required capacity before supplying it to consumers. The electricity supply for domestic consumers is 230 volts for the single-phase supply, and 400 volts for the triple-phase supply, with a range +10%, -6% and 50Hz ±1% of permitted frequency, which complies with MS IEC 60038 standards [1].

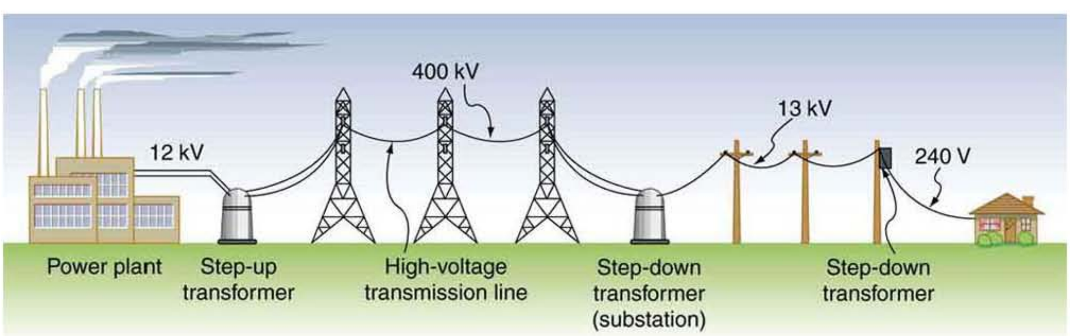

Figure 1.1: Overview of the Power system

The components of a power system need to be protected to ensure that a faulty power system is isolated from other live systems while keeping the rest of the system running continuously. Faults occur when two or more conductors operating with different potentials are unintentionally connected. Lightning, deterioration of insulation due to vandalism and tree branches are some of the causes of faults [2]. When faults occur in the system, the high current produced will flow through the transmission line damaging equipment located at the end of the network.

The protective components commonly used in the power system protection scheme are circuit breakers, transducers and relays. These components can isolate the faults by separating the network from high currents and voltage. When a fault occurs in a system, a voltage or current signal is transmitted to a relay by a transducer. The relay in turn operates a circuit breaker and clears the fault. The fault gives rise to abnormal voltages and currents that might be in the range of kV or kA. The transducer reduces them to much lower levels before transmitting the signal to the relay. This protection device should be connected to the grounding system to prevent potential differences between the device and the surrounding.

1.2 Grounding System

The National Electrical Code (NEC) [3] describes grounding as a conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the ground (earth mass), or to some conducting body that plays the role of the ground. In addition, grounding can also be defined as a low impedance path that turns the current to flow to the source [4]. The function of the ground circuit in a power system is to avoid any hazardous voltage in electrical devices.

The ground, acts as a reservoir for the charge, neutralizes an electric current. Electrical equipment with an excess of charge, either positive or negative, is removed and balanced by a process known as grounding, which acts by transferring the electrons between them [5]. During lightning or switching surge currents, grounding serves as the path for these fault currents to stabilize the voltage potential and act as a zero-potential reference point to ensure the safe operation of the power system, electrical equipment or human beings [6, 7].

A good and reliable grounding system must be designed to provide safety, protect building structures and equipment from unintentional contact with energized electrical lines, electrical noise reduction and to establish a reference [8]. Some electrical equipment surrounded by a metal case might become electrically energized due to the occurrence of faults. It could carry sufficient voltage that might result in an electrical shock to anyone who is in contact. Hence, any metal part of an electric equipment must be connected to a grounding electrode that is embedded in the earth, or to a building grounding system [8, 9]. A conductive surface is said to be grounded when it is effectively connected to the earth. In the case of a fault condition, the fault current is channelled into the earth, creating a short circuit that eventually trips the electric supply circuit breaker; thus, eliminating any hazardous voltage in the electrical devices or circuits [10, 11]. The fault current is then diverted into the ground and the equipment does not pose any danger when touched.

There are three important roles of ground resistance that ensures an effective grounding performance, namely;

i. Provide zero reference for the electrical service.
ii. Provide a low resistance path to protect against electrical faults.
iii. Protect equipment against static electricity and frame potential for personnel safety.

A simple grounding system in an electric system can be a conductor from electric circuit connected to iron pipe that is driven into ground. It provides a safe environment that protects personnel in the vicinity of the grounded facilities from danger of electrical shocks, particularly due to fault conditions [7]. Ground conductors must possess the lowest possible resistance path for fault currents leading to the surrounding soil while maintaining the step and touch voltages at an acceptable value [7, 12]. It should limit the potential with respect to general mass of the earth to ensure it protects the safety of the personnel and equipment. A good grounding system protects buildings and installations against lightning, provides safety for humans by limiting touch and step voltages to safe values, limiting electromagnetic disturbances, and has good power quality.

It is a real challenge to obtain earth electrodes with low ground resistance. A reliable system should be set-up with low resistance value ground connections. It is important to periodically check the earth's resistance because it might vary with changes in climate and temperature. For example, in some locations the ground water level is lower due to seasonal variations and this could change the earth's effective resistance in the vicinity.

Under fault conditions, soil resistivity is high and ground potential rise (GPR) could occur. Step potential is the voltage difference between the feet of a person when stepping into the fault point without touching any object that is planted on the ground, as depicted in Figure 1.2. The current flows through the body via the feet and the current value depends on the step distance. Touch potential on the other hand is the voltage between the energized object and feet of a person who is in contact with the object, as illustrated in Figure 1.2. The object can be energized in cases where the grounding resistance between the object and soil is high. It is desirable to have an earth electrode resistance that is as low as possible in order to prevent hazardous touch voltage. Its value should be maintained within the permissible limits even under fault conditions. Under such a situation, the grounding resistance should be low enough to guarantee the safety of the power system.

High earth resistance can lead to fatal injuries and even death if 30mA of currents pass through a human body [13]. In the case of lightning surge current under high earth resistance, voltage induced on the earth surface around the grounding electrode could easily reach dangerous levels.

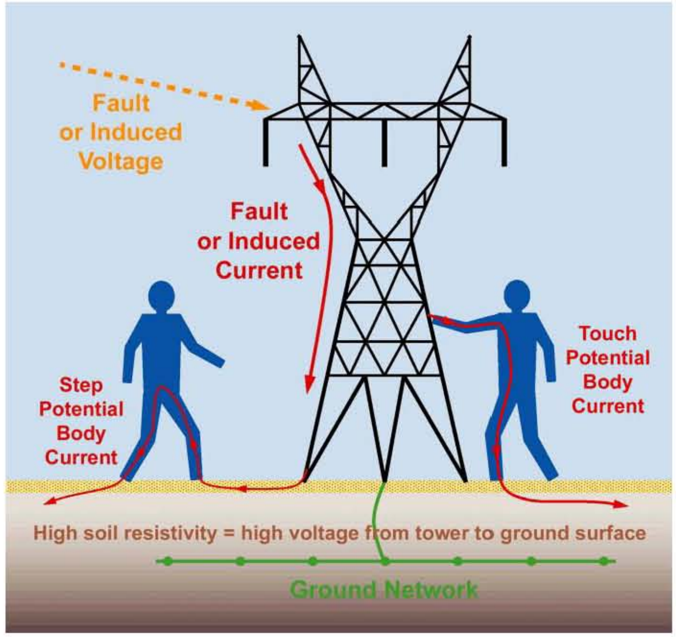

Figure 1.2: Effect on ground potential rise

1.3 Problem Statement

A grounding system is a fundamental countermeasure to guarantee the safe operation of electrical appliances and equipment. An efficient and reliable grounding system should provide zero voltage reference and any grounded object is presumed safe to touch. However, under certain circumstances, a dangerous voltage level could develop in the ground due to phase imbalances in a faulty system or unbalanced transient faults.

During an earth fault, the flow of current to the earth produces a high ground potential rise (GPR) in the grounding system with respect to mother earth. This GPR is equivalent to the maximum fault current multiplied by the grounding grid resistance [14]. When earth-fault current flows from a grounding electrode to the surrounding soil, potential gradients emerge in the soil and also on the ground surface. The maximum value of the potential gradient as well as its most dangerous state is close to the location of the buried electrode, both in the soil and on the ground surface. The potential gradient decreases rapidly when the distance from the earth electrode increases.

A person walking on the ground surface adjacent to the earth electrode during earth fault could be subjected to a ground potential difference that could cause a current to flow from one foot to the other through the human body.

Many researchers and engineers have attempted various approaches to decrease the grounding resistance such as by using long vertical grounding electrodes [15], adding multiple numbers of grounding electrodes [16] and changing soils around the grounding grid with low resistivity materials [10, 17]. In some cases, these might not be the best solution to eliminate the problems.

The grounding system is usually placed at a distance from the electrical equipment, such as on high rise buildings or large-scale buildings; hence, this results in a lengthy grounding conductor that leads to an increase in the resistance at the path. During thunderstorms, the grounding conductors (above the ground surface) could experience induced voltage and current impulse due to lightning strikes. The discharge from these induced voltage and current results in ground potential rise occurring at various parts of the building. The phenomena might trigger side flashovers on humans, equipment and others materials due to the rise in step voltage and touch voltage.

The potential relative to a point on earth is highest at the point where the current enters the ground, and decreases with the distance from the source. GPR is concerned with the design of the electrical grounding system because a high potential rise could be hazardous to people or equipment. The change of voltage over distance (potential gradient) could be extremely high and this could damage the connected equipment and nearby persons within the grounding distance. Any conducting object connected to the grounding system might also be energized at the ground potential in the grounding system. This transferred potential rise is hazardous to people and equipment nearby.

As an approach to address this issue, revolutionising the grounding system leads to the enhancement of the enhanced ground electrode (E.G.E). The E.G.E, also known as portable grounding, is expected to provide an efficient grounding system with zero voltage reference. The potential difference between the source and the ground is minimized by placing E.G.E close to the equipment, which could effectively shorten the grounding conductor [18]. The E.G.E material used should focus on its own characteristics.

1.4 Objectives

The main aim of this research was to propose a new revolution in portable grounding systems with enhanced performance. In order to achieve this, the following objectives need to be fulfilled:

i. To design and fabricate an E.G.E prototype with improved electrical characteristics for zero potential reference points.

ii. To analyse and evaluate performances of E.G.E grounding materials in terms of resistivity, structural morphology and element compositions as well as the electrode design in terms of heat dispersion.

iii. To validate the electrical performance of E.G.E under lightning strike conditions and prolog its life expectancy.

1.5 Scope of Study

This research investigation focused on the following scope of study:

i. An E.G.E. prototype limited in size measuring 19.5 cm x 19.5 cm x 11.5 cm due to compactness size. E.G.E was filled up with four potential samples of grounding compounds, which were kaolin, bauxite, sand and charcoal. A grounding electrode measuring 0.5 cm in diameter and 20 cm length made of copper material was attached to the grounding compound.

ii. Three design models of the grounding electrode had simulated heat transfer configurations by using the FEM package presented in a 2D model.

iii. The E.G.E was tested under four different configurations, as discussed in Section 3.7, with 2cm gaps across the HV plate and LAT, and limited to withstand a high voltage discharge of up to 100kV under impulse and standalone working conditions at the HV Laboratory in UTHM for 1 year in a dry state and running in ambient temperature, during morning from 8 am to 10 am.

1.6 Contribution of the Present Work

The major contributions and achievements of this research are summarised as follows:

i. Bauxite is identified as the best grounding material, as supported by experiments conducted in regards to its morphological characteristics, element composition characteristics and resistivity. Furthermore, bauxite has been never tested before [19-21].

ii. Root-like dangling is a new design approach for grounding electrodes that have been well modified based on previous research studies [22].

iii. E.G.E is proven by sustaining a good performance as a grounding system based on results of tests using a lightning impulse voltage on the E.G.E prototype.

1.7 Organization of the Thesis

This thesis is divided into five chapters.

CHAPTER 1 introduces the thesis and presents the context of the research work including the research background, problem statements, objectives, scopes, and describes the structure of the thesis.

CHAPTER 2 provides a review of numerous previous works and published literature such as books, journals, published thesis and technical websites regarding the study undertaken. An overview of the grounding system, including the purpose of grounding, conventional methods or designs of electrodes, factors affecting earth resistivity and standard of grounding are addressed and discussed in greater detail.

CHAPTER 3 proposes potential grounding compounds and grounding electrode designs and configurations. The method and technique for developing a prototype of an E.G.E is also described. It also presents the investigation of heat transfer using different electrodes in a computer simulation.

CHAPTER 4 illustrates the project's output and analysis of the results. Observation of heat transfer in an E.G.E are discussed under simulated conditions. Analysis of the best material for an E.G.E were obtained from laboratory testing.

CHAPTER 5 presents the conclusions of this study and some recommendations for the further investigation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of the study related to the grounding system concept. General insights into the grounding system focused on the design, components, and factors that affect the grounding system's performance. The review is to reach the lower resistance of grounding system.

2.2 Grounding system principle

The grounding system provides a connection between electrical equipment and the neutral point of a power system to ground.

The terms 'ground', 'permanent ground', and 'ground connections' are defined as "*electrical connections intentionally made between electrical bodies (or conducting bodies in close proximity to the electrical circuit) and metallic bodies in the earth, such as rods, water pipes, plates or driven pipes*" [23] . 'Metallic body' in this definition refers to an electrode. Meanwhile, IEEE-STD-1100 describes grounding as "*a conducting connection, whether intentional or accidental, by which an electric circuit or equipment* *is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth*"[24].

Grounding of electrical equipment involves a connection to the earth, as shown in Figure 2.1. The final connection to earth is after an electrode is buried into the earth. Safety is the primary concern of a grounding design. The IEEE STD 80-2000 [7] emphasizes two major objectives in a grounding design:

i. Provide a way to carry electric current into the earth under normal and fault conditions without exceeding any operational or equipment limits or affecting the continuity of services.
ii. To ensure that a person in the vicinity of the grounded facility is not exposed to the danger of a critical electric shock.

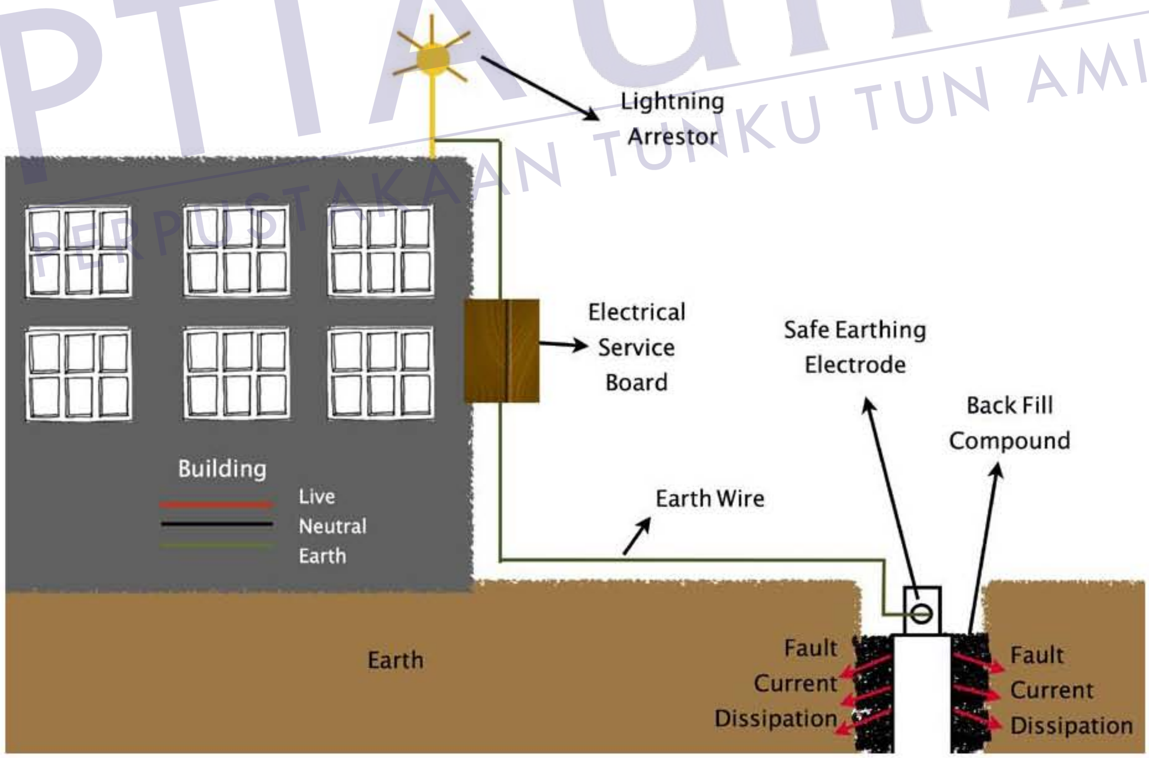

Figure 2.1: Connection of grounding system

A ground (earth) should be of zero ohm resistance. National Fire Protection Association (NFPA) and the Institute of Electrical and Electronics Engineers (IEEE) had recommended a ground resistance value of 5 ohms or less. NEC, as in NEC 250.56 [25], stated that system impedance to ground should be less than 25 ohms, while for a facility with sensitive equipment, the value should be 5 ohms or less. As for the telecommunications industry, 5 ohms is the accepted value, but for lightning protection, the arrestor should be coupled with a maximum ground resistance of 1 ohm.

2.3 Grounding system components

The ground is not a good conductor of electricity as soil resistivity is high. The effective way would be to implement a passage of current into and out of the earth. The electrical properties of grounding depend on two parameters, namely the grounding electrode configuration and soil resistivity.

2.3.1 Grounding electrode

Electrodes in the forms of rods, pipes and plates buried in the ground provide an effective connection to the general mass of the ground (mother earth) that could maintain ground potential in all the connected conductors. The electrode is the path for the current to travel and dissipate into the ground and it must be in contact with the soil. The right selection must be emphasized so that it will enhance the performance of the grounding system [4]. Suitable conductors are chosen for grounding the grid in order to provide satisfactory performance and maintain the quality of the grounding system for the long term. The electrode conductors and materials must be able to conduct high current capacity and easy to discharge current into the ground. The electrode basically consists of three components, namely ground conductor, connection of the ground conductor to the grounding electrode and the grounding electrode, as illustrated in Figure 2.2.

There are three locations of electrode resistance, as shown in Figure 2.2. First location is at the resistance of the electrode and all the conductors or leads connected to

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